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Review of the Sediment Delivery Ratio
Techniques Component of the Highland
Silver Lake Watershed Project

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Division of Water Pollution Control
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Techniques Component of the Highland Silver Lake Watershed Project
by

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In Cooperation With:

Soil Conservation Service, USDA

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Technical Report
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Abbreviations

IEPA:	Illinois Environmental Protection Agency
SCS:	Soil Conservation Service
RMS's:	Resource Management Systems
RCWP:	Rural Clean Water Program
NPS:	Nonpoint Source
Ac:	Acre
ha:	hectare
ISCC:	Illinois State Coordinating Committee
Fig.:	Figure
SDR:	Sediment Delivery Ratio
A:	Area
Mi ² :	square miles
HP41CV:	Hewlett Packard Calculator
USLE:	Universal Soil Loss Equation
MCLCC:	Madison County Local Coordinating Committee
CP:	Cover and management factor, support practice factor

Preface

This report is a product of the Comprehensive Monitoring and Evaluation Program for the Highland Silver Lake Rural Clean Water Project. This project is one of five in the nation designed to evaluate the effectiveness of the U.S. Department of Agriculture (USDA) Rural Clean Water Program in (a) achieving improved water quality in an approved project area in the most cost-effective manner possible in keeping with the provision of adequate supplies of food, fiber and a quality environment, and (b) assisting agricultural landowners and operators to reduce agricultural non-point source water pollutants and to improve water quality in rural areas to meet water quality standards or goals.

Funding for the Rural Clean Water Program and Comprehensive Monitoring and Evaluation Program is provided by the USDA Agricultural Stabilization and Conservation Service. The U.S. Environmental Protection Agency is assisting USDA in evaluating the effectiveness of the Rural Clean Water Program in improving water quality. The USDA Soil Conservation Service, which provides technical assistance to the Rural Clean Water Program, is also responsible for oversight of the Comprehensive Monitoring and Evaluation Program. The University of Illinois Cooperative Extension Service provides education/information assistance in both programs.

Agencies participating in the Comprehensive Monitoring and Evaluation Program include: the Illinois Environmental Protection Agency, which is responsible for water quality monitoring and evaluation; the Illinois Department of Energy and Natural Resources State Water Survey, responsible for water quantity monitoring and evaluation; the USDA

Economic Research Service, responsible for the socio-economic evaluation of the project with assistance provided by the University of Illinois -- Department of Agricultural Economics, on the on-farm economic analysis; and the Southwestern Illinois Metropolitan and Regional Planning Commission, on the off-site economic analysis. The Commission is also responsible for coordination of the Comprehensive Monitoring and Evaluation Program for the Project. The University of Illinois Agricultural Experiment Station and the Illinois Department of Conservation are providing voluntary assistance on various aspects of the program.

The Illinois State Rural Clean Water Coordinating Committee is providing oversight for the Highland Silver Lake Watershed Rural Clean Water Project and assisting USDA and EPA in their comprehensive, joint water quality monitoring and evaluation, including coordination with the Local Coordinating Committee. Membership of the Illinois State Coordinating Committee consists of the following:

Illinois State ASC Committee; USDA

Farmers Home Administration; USDA

Cooperative Extensive Service; USDA

U.S. Forest Service; USDA

Soil Conservation Service; USDA

U.S. Environmental Protection Agency -- Region V

Illinois Environmental Protection Agency

Illinois Department of Agriculture, Division of Natural Resources

Illinois Department of Conservation

Economic Research Service; USDA

Illinois Department of Energy and Natural Resources-State Water Survey

Acknowledgement

The work described herein was a group effort of United States Department of Agriculture - Soil Conservation Service and Illinois Environmental Protection Agency personnel. Wayne Kinney, Peter Waldo, John Lowrey and Harvey Sundmacker of USDA-SCS participated in this project under the administrative guidance of State Conservationist John J. Eckes. Don Clarke from the SCS National Technical Center in Lincoln, Nebraska provided assistance and guidance during this effort. Mr. Tom Iivari, SCS - Northeast - NTC, provided review comments.

Mike Nation prepared most of the illustrations. Nancy Simpson and Susan Carlson provided invaluable assistance in obtaining the cited reference material. This report was typed by the Word Processing Unit under the direction of Norma Kraus and printed under the direction of Claude Pearson by the Print Shop.

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INTRODUCTION

Initial water quality management planning efforts documented that agricultural activities are a major source of pollution in Illinois and mandated the development of plans to control this nonpoint source (NPS) pollution from agriculture. The most severe agriculturally related problem identified was soil erosion, resulting in lake sedimentation (IEPA, 1979). Nationwide, approximately half of the total sediment delivered to lakes and streams is from cropland (Stewart, 1975). The effect of sediment on water quality is twofold -- physical effect and chemical interactions with constituents in the water column.

Sediment is defined as any solid material either mineral or organic which has been eroded, transported or deposited on land or in water. It is important to note that soil erosion is not synonymous with soil loss, nor is soil loss equal to sediment yield. In Illinois, erosion control is being used as surrogate for sediment control because sediment control is less amenable to quantitative analysis. The idea of using erosion control as a surrogate for sediment control reflects the current lack of knowledge concerning sediment origin, transport, deposition and control technology.

Management of agricultural lands for water quality purposes demands reliable tools for the prediction of sediment yields to the field edge. Sediment is the key link in the chain of understanding, predicting and controlling soil erosion and its impacts. Various predictive techniques have been developed that are utilized to quantify potential sediment source areas. The 1983 Annual review of the Highland Silver Lake

watershed Rural Clean Water Program (RCWP) highlighted the need to document off-site impacts of the erosion control/water quality practices being implemented. One of the primary technical needs of the Highland Silver Lake Watershed Project was the determination of sediment delivery ratios for sites where implementation has occurred, so as to ascertain the off-site impacts of the RMS implementation. One of the key components of this evaluation is predicting the impacts of RMS's implementation on sediment yield to the stream course and then the lake. This study was initiated to examine various predictive sediment delivery ratio estimation techniques and determine which technique should be utilized to determine the impact of erosion control on sediment yield for the Highland Silver Lake RCWP. This report presents the results of that examination.

HIGHLAND SILVER LAKE PROJECT

The Illinois Environmental Protection Agency (IEPA) in cooperation with various United States Department of Agriculture Agencies, State Agencies and local organizations, is evaluating the impact of Resource Management Systems (RMS's) implemented under the RCWP Project in the Highland Silver Lake Watershed, Madison County, Illinois. Due to the agricultural base of the watershed, the nonpoint source pollutants of greatest concern in Highland Silver Lake are sediment, nutrients and pesticides (ISCC, 1983). These pollutants can impair the following intended uses of the water resource; drinking water supplies, fisheries and wildlife, recreation, industrial and agricultural. The primary pollutant of concern within the watershed is sediment. The primary objective of the comprehensive monitoring and evaluation project is to evaluate the impact of the implementation of the agricultural NPS control strategy prescribed by RCWP process upon Highland Silver Lake.

DESCRIPTION OF HIGHLAND SILVER LAKE WATERSHED

The Highland Silver Lake Watershed encompasses approximately 31,000 acres (12,399 ha) in northeastern Madison County, Illinois (Fig. 1). It drains into Highland Silver Lake through Silver Creek and its numerous tributaries.

Highland Silver Lake was constructed in 1962 by the City of Highland as a public water supply. It is utilized for recreation, and flood control as well as a water supply for the City of Highland.

The land use in Highland Silver Lake Watershed is predominantly agricultural. The production of row crops (82% of the land) and livestock are the major agricultural enterprises in the watershed. The predominant crop in the watershed is soybean (48 percent of the cropland acreage). Corn, wheat and forage crops are also important crops. There are approximately 116 acres (46.9 ha) of feedlot operations within the watershed. The terrain is relatively flat and the soil has a high detachment potential due to the influence of sodium on the fine-textured soils. Agricultural land use and management practices also contribute to this high rate of soil detachment. Sediment delivery to the watercourses appears to be enhanced by the preponderance of roadside and field ditches that route sediment directly to small feeder streams. The ditch network is necessary due to the high watertable and the flat topography to insure adequate drainage of the agricultural lands.

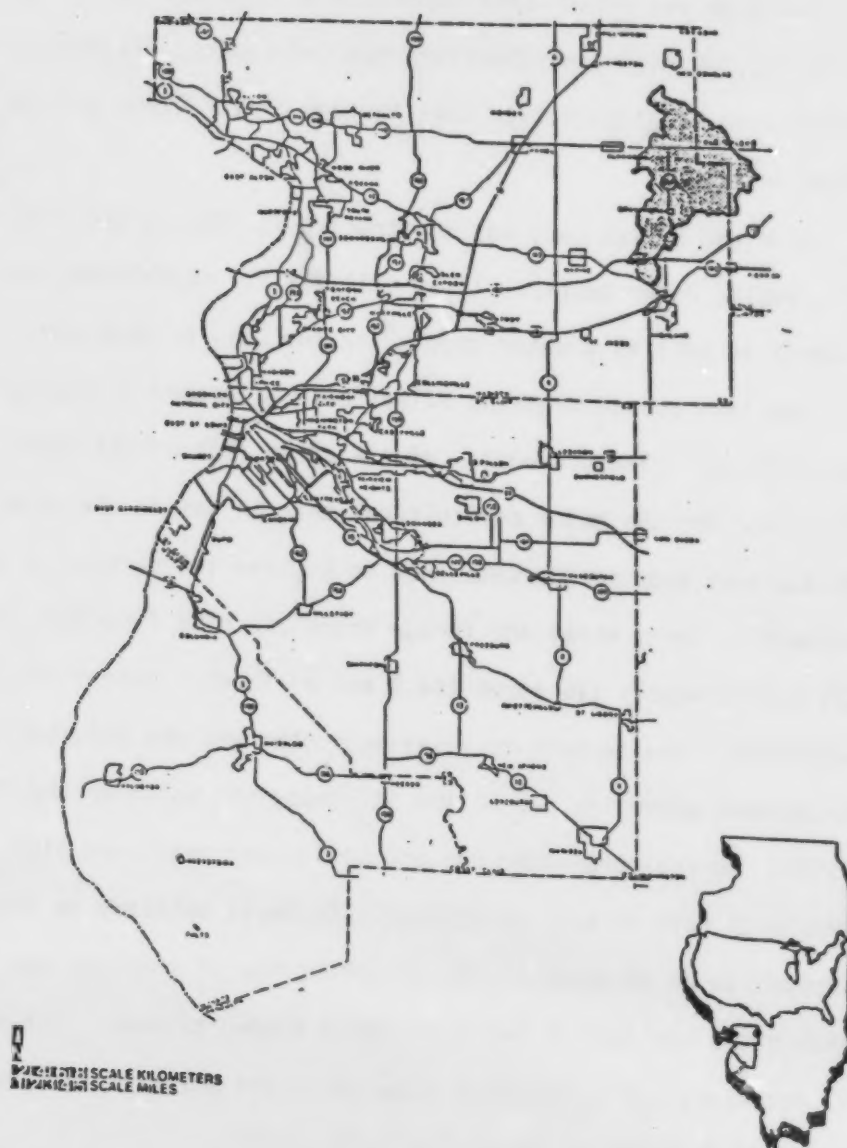


Figure 1: Regional Location of the Highland Silver Lake Watershed.

TABLE 1

Land use/cover in the Highland Silver Lake Watershed, 1981,
by acres and percent. (ISCC, 1982)

Land Use/ Cover	# of Acres	(ha)	%
Cropland	25,205	(10,200.5)	82.3
Pasture/Hayland*	1,662	(672.6)	5.4
Woodland	1,250	(505.9)	4.1
Urban	210	(85.0)	0.7
Feedlots	116	(46.9)	0.3
Interstate Highway	49	(19.8)	0.2
Wildlife	327	(132.3)	1.1
Farmsteads	619	(250.5)	2.0
Residential	356	(144.1)	1.2
Gravel Pits	15	(6.1)	0.0
<u>Water</u>	<u>830</u>	<u>(335.9)</u>	<u>2.7</u>
Total	30,639	(12,399)	100

FIELD SITE SEDIMENT DELIVERY RATIO STUDY

The ratio of sediment yield to the amount of gross erosion is defined as the sediment delivery ratio. Predictive techniques are utilized to estimate the sediment delivery ratio, when sediment yield information is not available. An earlier sediment delivery ratio calculation based on gross soil erosion estimates and a lake sediment survey indicated the watershed sediment delivery ratio was approximately 47% (Davenport, 1982). Since this is a watershed wide delivery ratio and not site-specific to the areas critically impacting water quality, there was concern that applying a watershed-based sediment delivery ratio would underestimate the off-site impact of RMS implementation in the critical area. Evaluation of the relative impact of RMS implementation upon water quality requires the development of site-specific sediment delivery ratios to facilitate measurement of sediment yield to local stream courses. The predictive sediment delivery ratio technique selected must be easily applied. Also it should be able to accommodate variations in sediment transport characteristics that are site specific.

Techniques

Nine predictive sediment delivery ratio techniques were included in this study. These can be categorized into three general types: 1) area-based, 2) based on sediment transport factors and 3) combination or variations of categories 1 and 2. A brief description of the methods included in this study is provided below.

I. Roehl (1962):

$$\frac{SDR}{XSDR} = \left(\frac{XArea}{Area} \right)^{0.2}$$

Area (square miles)

X: measured value

Data from southeastern United States was utilized in developing this method. Drainage areas ranging in size from 0.55 to 28.8 square miles were utilized in developing this equation.

II. LRA (1970): $SDR = \text{Area}^{-0.1}$
Area (square feet)

This equation was developed as part of the Upper Mississippi River Comprehensive Basis Study. Analysis of 15 USDA-SCS Land Resources Areas (LRA) was made in order to correlate sediment deliveries ratios to drainage areas.

III. Vanoni (1975): $SDR = 0.47 A^{-0.125}$

A: area (square kilometers)

This equation is based on approximately 300 watersheds from all over the country. Ranging in size from 1 to 10,000 square miles.

IV. Walter's method incorporates two factors; size of the field and distance from the field to the stream. Walter's procedure is intended as a guide for identifying the relative magnitude of sediment sources. It is only to "be used in the context of planning and identifying critical problem areas, establishing priorities, and forming general solutions" (Walter 1982).

V. "Pete" method evaluated in this study for determining sediment delivery ratios for sheet and rill erosion, quantifies topographic and cover factor changes along a hillside. It also incorporates a consideration of the area weighted USLE soil loss involved, because delivery ratios for sheet and rill erosion apparently are proportional to the relative fractions of soil loss controlled in the entrainment/transport/deposition process. Weighted, rather than gross total, soil loss values are used, because the slope profiles studied at

the sample points are complex in nature. An outstanding assumption in this procedure is that the topographic changes in slope profiles are the most consistent variable affecting sediment delivery ratios for sheet and rill erosion in Illinois (Waldo, 1982).

VI. Clarke procedure operates on the quantification of topographic and management features along overland flow profiles selected to be representative of watersheds. This procedure encompasses the concept that a downslope reduction in slope gradient, cover factor or support practice factor value is accompanied by a proportional reduction in transport capacity and that deposition is proportional to the reduction in transport capacity. The amount of sediment influenced by a downslope reduction in a transport factor value and soil loss rate upslope from the point where deposition is indicated (Clarke, 1983).

VII. Boyce procedure incorporates: slope steepness, USLE cover and support practices, slope configuration and upslope/downslope 'CP' (cover and management - support factors) ratios. This is a multiple field method due to the upslope/downslope adjustment factors (Boyce, 1981). Procedure was utilized in this study without the adjustment factor.

VIII. The SCS method is a general guide for determining sediment delivery ratios based upon land slope and land form. The land form categories are concave and convex slopes. The general guide was developed on data collected in twelve watersheds within the State of Illinois under the River Basin Study Program by SCS. In order to determine a sediment delivery ratio with this method a field survey of land slope must be made. It is primarily used on soil mapping units then extrapolated to larger areas. (SCS, 1984).

IX. CREAMS (Chemical, Runoff, and Erosion from Agricultural Management Systems) is a mathematical model developed to evaluate nonpoint source pollution from field-sized areas (Knisel, 1980). It was designed to be used as a planning tool for comparing the relative impact of various RMS alternatives, not necessarily to predict actual quantities of pollutants. CREAMS was the only mathematical simulation model utilized in this study.

Only the overland flow element of the erosion/sediment yield component was utilized for the purpose of calculating sediment delivery ratios. Sediment delivery ratios were annualized over the life of the rotation for the simulated period of time.

Study Sites

Two field sites within the Highland Silver Lake Watershed were selected for this study (Fig. 2). On both sites water quality/quantity sampling equipment was installed to measure actual sediment yield from these sites. Due to the lack of adequate measured information, no estimate of sediment yield has been made from the monitoring data at this time; so comparison between measured data and the various predictive technique is not possible.

Field Site 1 is a 58 acre (23.5 ha) single crop watershed draining into the East Fork of Silver Creek. The watershed is characterized as relatively level, with a 50-50 mix of Darmstadt -- Oconee Silt loam and Herrick -- Piasa Silt loam complexes. Figure 3A shows the site. The rotation is soybeans, wheat -- double cropped soybeans and corn.

Field Site 2 is a 36 acre (14.6 ha) watershed draining into a tributary of the East Fork of Silver Creek. The watershed is relatively level in the upper portion, transforming into a steeper slope topography toward the field outlet. Figure 3B shows the site. The present rotation is soybeans, wheat-double cropped soybeans and corn.

Results

There is considerable variation among the various techniques. Table 2 presents the results of applying sediment delivery ratio predictive techniques to Site 1 within the Highland Silver Lake Watershed. The predicted sediment delivery ratios range from 24 to 100% and average of 68%. Experienced field personnel (SCS, IEPA), after a field review, estimated the sediment delivery ratio to be approximately 65%.

Table 3 shows the results of applying these same techniques to Site 2. The predicted values ranged from 22 to 100% and averaged 69. Experienced field personnel (erosion control), after a field examination estimated the sediment delivery ratio to be 75%.

CREAMS was designed so as not to require calibration, although calibration is feasible (Knisel, 1980) and was not calibrated for this site. The lack of calibration could cause an error in the variables simulated by the hydrologic component of CREAMS, which drives the overland flow erosion/sediment yield component of the model. Sediment delivery ratios based on combining an overland flow erosion/sediment yield and Universal Soil Loss Equation (USLE) predictions are artificially contrived. This is a hybrid CREAMS sediment delivery ratio since the erosion estimate (USLE) compared to the CREAMS overland flow erosion/sediment yield was not generated for the same climatic conditions. Error could occur if CREAMS is applied to: 1) a short term (10 years) simulation based upon actual precipitation combined with the USLE, a long (22 years) term average. The model does not predict potential soil erosion for the simulate period. The CREAMS model is data

and labor intensive to run, due to its complex nature. This is a serious drawback for its use in determining site-specific sediment delivery ratios for all sites where RMS's are being implemented within the watershed. Another drawback is that there are sites within the watershed, where the application of the CREAMS model could not be made without violating basic assumptions under which the model was designed to be use. These two drawbacks preclude its use for developing site-specific sediment delivery ratios for the Highland Silver Lake Project.

Boyce's method has to be considered less applicable than the others when attempting to estimate Site 1 or 2s' sediment delivery ratio because one of the adjustment factors doesn't apply to this situation: Boyce's method has a multiple field adjustment factor but neither Site 1 or 2 are composed of multiple fields. Without the adjustment factor, final sediment delivery ratio equals initial sediment delivery ratio (100%). A multiple field study site was not selected because RMS implementation is field specific.

Figure 2

HIGHLAND
SILVER LAKE
WATERSHED

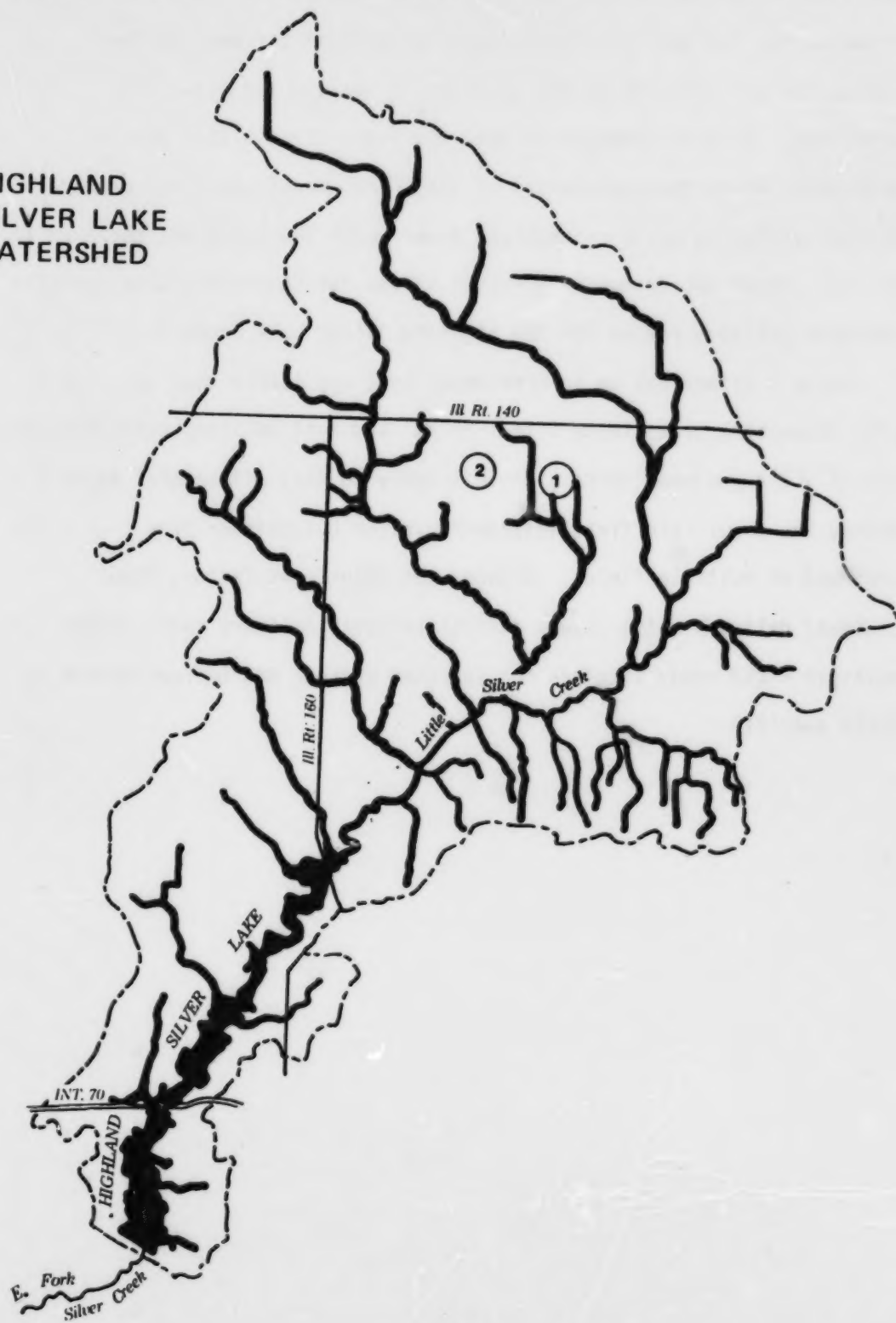




Figure 3A. Field site 1. Soils listed in Appendix section

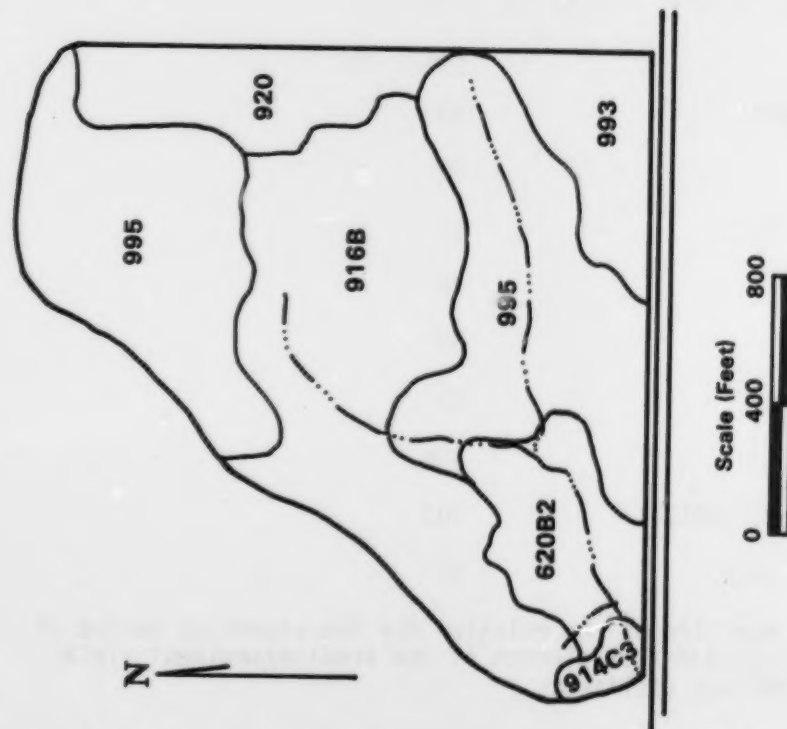


Figure 3B. Field site 2. Soils listed in Appendix section

TABLE 2

Sediment delivery ratio by method for Site 1.

<u>Method</u>	<u>Ratio (%)</u>
"Pete" (Waldo, 1982)	70
SCS (1984)	82
Clarke (Waldo, 1982)	73
Vanoni (1975)	56
Roehl (1962)	44
LRA (UMRBC, 1970)	24
Walter (1982)	100
Boyce (unpublished, 1981)	100
CREAMS* (Knisel, 1980)	61

*Annualized over the life of the rotation for the simulated period of time. Only the overland flow element of the erosion/sediment yield component of CREAMS was utilized.

TABLE 3

Sediment delivery ratio by method for Site 2.

<u>Method</u>	<u>Ratio (%)</u>
"Pete" (Waldo, 1982)	93
SCS (1984)	92
Clarke (Clarke, 1982)	91
Roehl (1962)	45
Vanoni (1975)	59
LRA (UMRBC, 1970)	23
Walter (1982)	100
Boyce (unpublished, 1981)	100
CREAMS* (Knisel, 1980)	22

*Annualized over the life of the rotation for the simulated period of time. Only the overland flow element of the erosion/sediment yield component of CREAMS was utilized.

Roehl, LRA and Vanoni methods are area based extrapolations from measured data. Most of the data utilized in the development of these area-based sediment delivery ratio techniques were taken from large areas in specific geographic regions of the country. These area-based techniques are considered less applicable for the purposes of determining site-specific sediment delivery ratios because this would be extrapolating the area-based methods beyond the drainage area sizes limits the original equations are based on. All of the area-based methods shows sediment delivery ratios vary inversely with drainage area size.

The Clarke and "Pete" methods show considerable promise because they incorporate percent, length, and configuration of slope, as well as vegetative cover impacts. A review of current literature indicated that these were important factors to be accounted for when determining sediment yield. It is important to note that the Clarke and "Pete" methods will not give the same answer for sediment yield from complex slope profiles, even though they consider the same factors in their equations. Each uses a different equation to compute the sediment delivery ratio. Site 1 has a complex slope profile. On drainage areas with a complex slope profile, the Clarke method would appear to be preferable to the "Pete" method. The "Pete" method uses an equation which approximates the amount of sediment trapped on the slope. Clarke's equation is more closely analogous to a sediment transport equation, and predicts the sediment delivery ratio associated with the toe of the slope. Both methods compute erosion using the same version of a USLE weighted to account for changes in slope. (Personal Communication, Waldo).

Applicability of various sediment delivery ratio predictive techniques varies by site. As noted earlier, review of current literature indicated, that when rainfall is equal, percent slope, slope length, slope configuration and vegetative cover were important factors in determining sediment yield. Therefore, these factors should be components in equations utilized for predicting sediment delivery.

Two of the methods studied incorporate these important factors: the "Pete" and Clarke methods. The "SCS" method is partially based on these factors. Application of both the Clarke and "Pete" methods produce similar sediment delivery ratios, considering the accuracy of the USLE; it is therefore assumed application of either technique would result in approximately the same sediment yield for the field. Since the "Pete" method is loaded on the HP41CV and was developed from information gathered in Illinois it was selected as the sediment delivery technique to be utilized in the Highland Silver Lake Project. The information collected for the "Pete" method is the same as that required for both the Clarke method and for USLE computations. A field data form is included in the appendix section. The Clarke method will be utilized for research purposes at the end of the Highland Silver Lake RCWP Project. Both the Clarke and "Pete" methods will be compared against measured data at the end of the monitoring period.

A distance to stream component is important in determining actual off-site impacts of the sediment. Since the sediment delivery ratio predicative techniques (except Walter, 1982) included in this study were not sensitive to location of source areas in respect to the stream

network, they are not useful for evaluating controls on specific fields in relation to the stream network impact unless modified. To determine the sediment yield to a water course, a correction factor must be applied to the computed sediment yields at the edge of the field. In order to accommodate this need, zones of transport efficiency were established.

Field reviews of the watershed and discussions with Highway Maintenance Department personnel indicated little sediment deposition occurred in the drainage and field ditch network. This is probably the result of the particle size composition of the sediment consisting of mainly fines (Davenport, 1984) and the dispersive influence of sodium on the soil particles, thus keeping them in suspension longer than normal. Density of vegetation in the drainage ditch did not appear to have a significant impact on the sediment deposition, so it was ignored in determining the correction factors. During the field review it was determined that distance from the stream network was an important component to be included in determining a correction factor for sediment transport to the stream network. Land slope will also be included in this correction factor. Two zones of transport efficiency were established based on distance from stream and watershed slope (Fig. 4):

- 1). If the drainage outlet is less than one-quarter of a mile from the stream network a correction factor of 0.90 will be applied. This zone corresponds to the more steeply sloping lands within the watershed.
- 2). If the drainage outlet of the field is more than one-quarter of a mile from the stream network a correction factor of 0.80 will be applied. This zone corresponds to the flat table lands of the watershed.

**HIGHLAND
SILVER LAKE
WATERSHED**

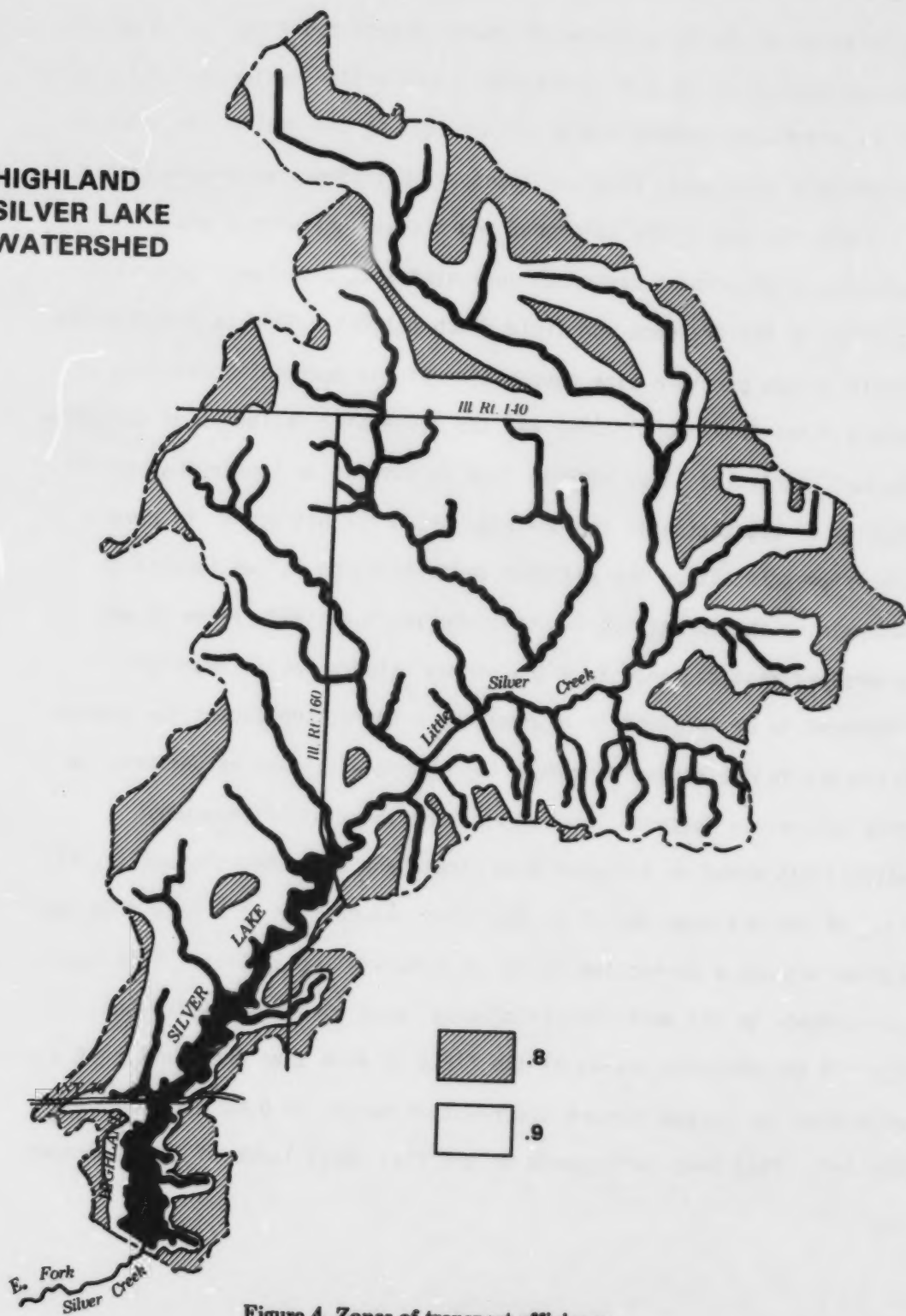


Figure 4. Zones of transport efficiency

SUMMARY

This study indicates that the off-site impact of Resource Management Systems (RMS) implementation funded under the Highland Silver Lake Watershed RCWP Project has probably been underestimated. The site specific sediment delivery ratios for both field sites were considerably higher than the previously estimated basin-wide ratio of 47% (Davenport, 1982).

The "Pete" method will be utilized to determine sediment delivery ratios on all sites where RMS implementation will occur in the future. An effort will be undertaken during 1985 to apply the "Pete" method to the sites where RMS implementation has occurred since project inception to the present. A weighted sediment delivery ratio will be determined for fields with complex drainage patterns. Distance from stream correction factors will be applied to fields not directly adjacent to the stream network. The correction factor multiplied by the total sediment yield predicted from the "Pete" sediment delivery ratio method will constitute the estimated sediment yield to the stream network.

Once RMS implementation funded under RCWP has been completed, total reduction of sediment yield to the stream network will be calculated. This calculated reduction will be compared to a 60% sediment yield reduction goal developed for the Highland Silver Lake Watershed RCWP Plan of Work (MCLCC, 1980).

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List of Publications Pertaining
to the Highland Silver Lake
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Appendix Section

APPENDIX A

Selected Key Definitions of Terms Used in This Report

Soil erosion - The process of detachment and movement of soil from the land surface by wind or water.

Soil loss - The amount of soil moved from its original position on a field or hillside.

Sediment Yield - Amount of sediment which moves off a unit area.

Sediment Delivery Ratio - the ratio between sediment delivery and soil erosion.

Sediment Delivery - Sediment that is transported to a specific point.

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APPENDIX B
FIELD DATA FOR DELIVERY RATIO (S_{DR}) COMPUTATIONS

Project _____ Sample No. _____

Soil Map Unit _____ Location _____

Date _____ K _____ Name _____

SLOPE DATA

Segment	Slope Angle	Length	Characteristics	Segment	Slope Angle	Length	Characteristics

COVER DATA

Zone	Width	Land Use	Crop Sequence	Tillage System, Practices	Canopy Type	Canopy Cover, %	Ground Cover Type	Ground Cover, %	C-value	P-Value

SKETCH